

Chapter 3
HISTORY OF COASTAL ENGINEERING

EM 1110-2-1100
(Part I)
30 April 2002

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Chapter 1-3 History of Coastal Engineering

I-3-1. Ancient World

The history of coastal engineering reaches back to the ancient world bordering the Mediterranean Sea, the Red Sea, and the Persian Gulf. Coastal engineering, as it relates to harbors, starts with the development of maritime traffic, perhaps before 3500 B.C. Shipping was fundamental to culture and the growth of civilization, and the expansion of navigation and communication in turn drove the practice of coastal engineering. The availability of a large slave labor force during this era meant that docks, breakwaters, and other harbor works were built by hand and often in a grand scale similar to their monumental contemporaries, pyramids, temples, and palaces. Some of the harbor works are still visible today, while others have recently been explored by archaeologists. Most of the grander ancient harbor works disappeared following the fall of the Roman Empire. Earthquakes have buried some of the works, others have been submerged by subsidence, landlocked by silting, or lost through lack of maintenance. Recently, archaeologists, using modern survey techniques, excavations, and old documents, have revealed some of the sophisticated engineering in these old harbors. Technically interesting features have shown up and are now reappearing in modern port designs. Common to most ancient ports was a well-planned and effectively located seawall or breakwater for protection and a quay or mole for loading vessels, features frequently included in modern ports (Quinn 1972).

Most ancient coastal efforts were directed to port structures, with the exception of a few places where life depended on coastline protection. Venice and its lagoon is one such case. Here, sea defenses (hydraulic and military) were necessary for the survival of the narrow coastal strips, and impressive shore protection works built by the Venetians are still admired. Very few written reports on the ancient design and construction of coastal structures have survived. A classic treatise by Vitruvius (27 B.C.) relating the Roman engineering experience, has survived (Pollio, Rowland, and Howe 1999). Greek and Latin literature by Herodotus, Josephs, Suetonius, Pliny, Appian, Polibus, Strabo, and others provide limited descriptions of the ancient coastal works. They show the ancients' ability to understand and handle various complex physical phenomena with limited empirical data and simple computational tools. They understood such phenomena as the Mediterranean currents and wind patterns and the wind-wave cause-effect link. The Romans are credited with first introducing wind roses (Franco 1996).

I-3-2. Pre-Roman Times

Most early harbors were natural anchorages in favorable geographical conditions such as sheltered bays behind capes or peninsulas, behind coastal islands, at river mouths, inside lagoons, or in deep coves. Short breakwaters were eventually added to supplement the natural protection. The harbors, used for refuge, unloading of goods, and access to fresh water, were closely spaced to accommodate the safe day-to-day transfer of the shallow draft wooden vessels which sailed coastwise at speeds of only 3-5 knots.

Ancient ports can be divided into three groups according to their structural patterns and the development of engineering skill (Frost 1963).

- a. The earliest were rock cut, in that natural features like offshore reefs were adapted to give shelter to craft riding at anchor.

- b. In the second group, vertical walls were built on convenient shallows to serve as breakwaters and moles. Harbors of this type were in protected bays, and often the walls connected with the defenses of a walled town (for example, ancient Tyre on the Lebanese coast). Often these basins were closeable to traffic using chains to prevent the entry of enemy ships (Franco 1996).
- c. The third group were harbors that were imposed on even unpromising coasts by use of Roman innovations such as the arch and improved hydraulic cement. Projects like this required the engineering, construction, and financing resources of a major empire.

All ancient ports had one thing in common: they had to be kept clear of silt at a time when mechanical dredging was unknown. This was accomplished by various means. One was by designing the outer parts of the harbor so that they deflected silt-bearing currents. The second was by allowing a controlled current to flow through the port or by flushing it out when necessary by means of channels. For example, at Sidon, a series of tanks (like swimming pools) were cut into the harbor side of a natural rock reef. The tanks filled with clear water that was held in place with sluice gates. When the gates were opened, currents of clear water would flush the inner harbor. Documentary and archaeological evidence show that both Tyre and Sidon were flourishing and powerful ports from the Bronze Age through the Roman era and must therefore have been kept clear of silt for over a thousand years (Frost 1963). Another method of preventing silt consisted of diverting rivers through canals so that during part or much of the year, the flow would enter the sea at location well away from the harbor.

The origins of breakwaters are unknown. The ancient Egyptians built boat basins with breakwaters on the Nile River at Zoser's (Djoser) step pyramid (ca. 2500 B.C.) (Inman 2001). The Minoans constructed a breakwater at Nirou Khani on Crete long before the explosion of Santorini (Thera) in ca. 1500 B.C. The breakwater was small and constructed of material taken from nearby dune rock quarries (Inman 1974, Figure 4). In the Mediterranean, size and sophistication of breakwaters increased over time as the Egyptian, Phoenician, Greco-Macedonian, and Roman civilizations developed and evolved. Breakwaters were built in China but generally at a later date than in the Mediterranean.

Probably the most sophisticated man-made harbor of this era was the first harbor of Alexandria, Egypt, built west of Pharos Island about 1800 B.C. by the Minoans. The main basin, built to accommodate 400 ships about 35 m in length, was 2,300 m long, 300 m wide and 6-10 m deep. Large stone blocks were used in the many breakwaters and docks in the harbor. Alexander the Great and his Greek successors rebuilt the harbor (300-100 B.C.) in monumental scale. The Island of Pharos was joined to the mainland by a 1.5 km breakwater with two openings dividing two basins with an area of 368 hectares (910 acres) and 15 km of quay front. Alexandria is probably best known for the 130m-high lighthouse tower used to guide ships on a featureless coast to the port from 50 km at sea. The multi-storied building was built with solid blocks of stone cemented together with melted lead and lined with white stone slabs. Considered one of the Wonders of the Ancient World, it eventually collapsed due to earthquakes between 1326 and 1349 (Franco 1996, Empereur 1997).

Another feature of the Greek harbors was the use of colossal statues to mark the entrances. Colossal statues of King Ptolemy, which stood at the base of the lighthouse, have been found with the lighthouse debris. Historians report the most famous harbor statue was the 30 m high Colossus of Rhodes, which stood on the breakwater heads. Three ancient windmill towers are still surviving upon the Rhodes breakwater (Franco 1996). Frost (1963) notes that the Greeks had used hydraulic cement long before the Romans.

I-3-3. Roman Times

The Romans introduced many revolutionary innovations in harbor design. They learned to build walls underwater and constructed solid breakwaters to protect exposed harbors. They used metal joints and clamps to fasten neighboring blocks together and are often credited with discovering hydraulic cement made with pozzolanic ash obtained from the volcanic region near Naples, which hardens underwater. Frost (1963) notes that the Greeks had used hydraulic cement long before the Romans. The Romans replaced many of the Greek rubble mound breakwaters with vertical and composite concrete walls. These monolithic coastal structures could be built rapidly and required little maintenance. In some cases wave reflection may have been used to prevent silting. In most cases, rubble or large stone slabs were placed in front of the walls to protect against toe scour. The Romans developed cranes and pile drivers and used them extensively in their construction. This technology also led them to develop dredges. Another advanced technique used for deep-water applications was the watertight floating cellular caisson, precursor of the modern day monolithic breakwater. They also used low, water-surface breakwaters to trip the waves before they reached the main breakwater. The peculiar feature of the vertical wall breakwater at Thapsus (Rass Dimas, Tunisia) was the presence of vents through the wall to reduce wave impact forces. This idea is used today in the construction of perforated caisson breakwaters (Franco 1996).

Using some of these techniques, the Romans built sophisticated breakwaters at Aquileia, Italy (ca. 180 B.C.), and at Caesarea, Israel (ca. 20 B.C.). The southwestern breakwater at Caesarea contained a “forebreakwater” that acted as a submerged reef that “trips” the wave causing it to break and dissipate energy before encountering the main breakwater (Inman 2001).

The largest manmade harbor complex was the imperial port of Rome; the maritime town at the mouth of the Tiber River was named Portus (The Port). It is now some four km from the sea, partly buried under Rome-Fiumicino airport. Despite its importance to the capital of the empire, (300,000 tons/year of wheat from Egypt and France), the harbor always suffered siltation from the river. Trajan, who also built the ports of Terracina and Centumcellae, built Portus’ inner hexagonal basin. The port of Centumcellae was built just to serve his villa at a site with favorable rocky morphology. A grandiose engineering project between 107-106 B.C. created a sheltered bathing and boating retreat. Slaves from all parts of the empire excavated a harbor and hauled in massive stones to create an artificial harbor to dampen the force of the waves. After the decline of Portus, it became, and remains, the Port of Rome. After remaining unchanged for over 1,000 years, the inner Roman Basin, which was dredged from rock (200,000 m³ or 260,000 yd³), is still in use. Roman engineers also constructed harbors in northern Europe along the main waterways of the Rhine and Danube and in Lake Geneva. They became the first dredgers in the Netherlands to maintain the harbor at Velsen. Silting problems here were solved when the previously sealed solid piers were replaced with new “open”-piled jetties. In general, the Romans spread their technology throughout the western world. Their harbors became independent infrastructures, with their own buildings and storage sheds as opposed to the pre-Roman fortified city-enclosed harbors. They developed and properly used a variety of design concepts and construction techniques at different coastal sites to suit the local hydraulic and morphological conditions and available materials (Franco 1996).

The Romans also introduced to the world the concept of the holiday at the coast. The ingredients for beach holidays were in place: high population density coupled with a relatively high standard of living, a well-established economic and social elite, and a superb infrastructure of roads. From the end of the republic to the middle of the second century of the empire, resorts thrived along the shores of Latium and Capania, and an unbroken string of villas extended along the coast from the seashore near Rome to the white cliffs of Terracina. Fine roads connected these resorts to the capital, allowing both the upper crust and the masses to descend from sultry and vapor-ridden Rome to the sea. For five hundred years, the sybaritic town of Baiae reigned as the greatest fashionable beach resort of the ancient world. Seneca the Younger called Baiae a

“vortex of luxury and a harbor of vice,” an alluring combination that Romans found irresistible (Lenček and Bosker 1998).

I-3-4. Modern Age

After the fall of the Western Roman Empire, a long hiatus in coastal technology and engineering prevailed throughout most of the European world with a few exceptions. Little is recorded on civil engineering achievements during the Dark and Middle Ages. The threat of attack from the sea caused many coastal towns and their harbors to be abandoned. Many harbors were lost due to natural causes such as rapid silting, shoreline advance or retreat, etc. The Venice lagoon was one of the few populated coastal areas with continuous prosperity and development where written reports document the evolution of coastal protection works, ranging from the use of wicker faggots to reinforce the dunes to timber piles and stones, often combined in a sort of crib work. Protection from the sea was so vital to the Venetians, that laws from 1282 to 1339 did not allow anyone to cut or burn trees from coastal woods, pick out mussels from the rock revetments, let cattle upon the dikes, remove sand or vegetation from the beaches or dunes, or export materials used for shore protection (Franco 1996).

In England, coastal engineering works date back to the Romans, who recognized the danger of floods and sea inundation of low-lying lands. On the Medway, for example, embankments built by the Romans as sea defense remained in use until the 18th century (Palmer and Tritton Limited 1996). The low-lying lands, consisting of recently-deposited alluvial material, were exceedingly fertile but were also vulnerable to flooding from both runoff and storm surges. In the Middle Ages, the Church became instrumental in reclaiming and protecting many marshes, and monks reclaimed portions of the Fylde and Humber estuaries. In 1225, Henry III constituted by Charter a body of persons to deal with the question of drainage (Keay 1942).

Across the North Sea, the Friesland area of the Netherlands had a large and wealthy population in the period 500 - 1000 A. D., and increasing need for agricultural land led to building of sea dikes to reclaim land that previously was used for grazing (Bijker 1996). Water boards developed in response to the need for a mutual means to coordinate and enforce dike maintenance. These boards represent some of the earliest democratic institutions in the Netherlands.

Engineering and scientific skills remained alive in the east, in Byzantium, where the Eastern Roman empire survived for six hundred years while Western Rome decayed. Of necessity, Byzantium had become a sea power, sending forth fleets of merchant ships and multi-oared dromonds (swift war vessels) throughout the Black Sea and Mediterranean. When the weary soldiers of the first crusades reached Byzantium's capital city, Constantinople, in 1097, they were amazed and awed by its magnificence, sophistication, and scientific achievements. Constantinople was built on the hills overlooking the Golden Horn, a natural bay extending north of the Bosphorus. Marble docks lined the waterfront, over which passed the spices, furs, timber, grain, and the treasures of an empire. A great chain could be pulled across the mouth of the Golden Horn to prevent intrusion by enemy fleets. A series of watch towers extended along the length of the Sea of Marmara, the Bosphorus, and the south shore of the Black Sea, and the approach of an enemy fleet could be signaled to the emperor within hours by an ingenious code using mirrors by day and signal fires by night (Lamb 1930).

The Renaissance era (about XV - XVI centuries) was a period of scientific and technologic reawakening, including the field of coastal engineering. While the standards for design and construction remained those developed primarily by the Romans, a great leap in technology was achieved through the development of mechanical equipment and the birth of the hydraulic sciences including maritime hydraulics (Franco 1996). “The Italian School of Hydraulics was the first to be formed and the only one to exist before the middle of the 17th century” (Rouse and Ince 1963). Leonardo da Vinci (1465-1519), with his well-known experimental method, based on the systematic observation of natural phenomenon supported by intellectual reasoning and

a creative intuition, could be considered the precursor of hydrodynamics, offering ideas and solutions often more than three centuries ahead of their common acceptance. Some of his descriptions of water movement are qualitative, but often so correct, that some of his drawings could be usefully included in a modern coastal hydrodynamics text. The quantitative definition and mathematical formulation of the results were far beyond the scientific capabilities of the era. Even so, da Vinci was probably the first to describe and test several experimental techniques now employed in most modern hydraulic laboratories. To visualize the flow field, he used suspended particles and dyes, glass-walled tanks, and movable bed models, both in water and in air. The movement from kinematics to dynamics proved impossible until the correct theory of gravitation was developed, some two centuries later by Sir Issac Newton (Fasso 1987). The variety of hydro kinematics problems dealt with in da Vinci's notebooks is so vast that it is not possible to enumerate them all in this brief review. In the 36 folios (sheets) of the Codex Leicester (1510), he describes most phenomena related to maritime hydraulics. Richter (1970) provides an English translation of da Vinci's notebooks (Franco 1996). The scientific ideas of the Italian Renaissance soon moved beyond the confines of that country, to the European countries north of the Alps.

I-3-5. Military and Civil Engineer Era

After the Renaissance, although great strides were made in the general scientific arena, little improvement was made beyond the Roman approach to harbor construction. Ships became more sea-worthy and global navigation became more common. With global navigation came the European discovery of the Americas, Australia, New Zealand, Indonesia, and other areas of the world, soon followed by migration and colonization. Trade developed with previously unreachable countries and new colonies. France developed as the leader in scientific knowledge. The French "G'enie" officers, who, along with their military task, were also entrusted with civilian public works, are reportedly the direct ancestors of modern civil engineers. S'ebastien le Prestre de Vauban (1633-1707) was a builder of numerous fortresses and perfected the system of polygonal and star shaped fortifications. His most eminent public works project was the conversion of Dunkirk into an impregnable coastal fortress. Apart from the construction of several forts, there were extensive harbor and coastal works, including the excavation of canals and harbor basins, the construction of two long jetties flanking the entrance channel, and the erection of storehouses and workshops. A great lock, a masterpiece of civil engineering, was built at the entrance to the Inner Harbor. Vauban himself designed and supervised the lock construction. Unfortunately, no more than 30 years after its completion, the fortress was destroyed as a consequence of the Spanish War of Succession. Vauban's projects provide a good example of engineering methods and lucidity. They consisted of an explanatory memorandum, several drawings, and a covering letter. The memorandum had four sections: (1) general background of the scheme; (2) detailed descriptions of the different parts, with references to the drawings; (3) cost estimates; (4) features and advantages of the work. It was during this time that the term "Ingenieur" was first used in France, as a professional title for a scientifically-trained technician in public service.

While France enjoyed a leading position in Europe with regard to exact sciences and their applications to technical problems, a social and economic revolution later known as the "Industrial Revolution" was taking place in England. The riding-horse and the packhorse gave way to the coach, the wagon and the barge. Hard roads and canals replaced the centuries old soft roads and trails, dusty in dry weather and mud-bound during rains (Straub 1964). Steam power allowed industry to be concentrated in factories that required continuous supply of raw materials and export of manufactured goods.

In the 18th and 19th centuries, advances in navigation and mathematics, the advent of the steam engine, the search for new lands and trade routes, the expansion of the British Empire through her colonies, and other influences, all contributed to the revitalization of sea trade and a renewed interest in port works. As the volume of shipping grew, more vessels were needed and as the dimensions of the new vessels became larger,

increased port facilities were necessary. Ports of the world experienced growing pains for the first time since the Roman era, and, except for the interruption caused by two world wars, port needs continue to grow (Quinn 1972).

I-3-6. United States Army Corps of Engineers

Since the formation of the United States, Army engineers and the Corps of Engineers have been responsible for or intimately associated with a wide variety of civil projects and improvements to waterways, ports, and navigation systems. The following paragraphs summarize the history of the U.S. Army Corps of Engineers (USACE) and outline some of the Corps' early efforts in coastal and navigation improvements.

The origins of the USACE date to June of 1775, at the beginning of the American War of Independence, when the Second Continental Congress authorized General Washington to assign a "chief engineer" for the "grand army" (Parkman 1978). General Washington selected Colonel Richard Gridley, a seasoned artilleryman, who had been preparing a line of fortifications around Boston during the early weeks of the war. Military operations during the war underscored the need for an efficient body of engineers, and in March of 1779, the Continental Congress finally authorized a separate and distinct "corps of engineers," to be commanded by Louis LeBègue Du Portail, an officer recruited by the American mission in France. The corps was a vital unit of the Continental Army until disbanded in November 1783 with the arrival of peace.

When war between France and England broke out in the 1790s Congress authorized President Washington to begin construction of a system of fortifications along the coast. In 1802, in anticipation of the European belligerents signing a treaty of peace, Congress cut back and reorganized the army and created a separate corps of engineers, limited at that time to sixteen officers (Parkman 1978). The Act of March 16, 1802 had other far-reaching consequences, as it provided further that the Corps was to constitute the personnel of a military academy at West Point. Congress had recognized the almost complete absence of trained military and civil engineers in the United States, and, in effect, established a national college of engineering. West Point was the only school in the country to graduate engineers until 1824, when Rensselaer Polytechnic Institute was formed. Quickly becoming the growing nation's primary source of engineering expertise, the Corps first concentrated on constructing and maintaining strategically-placed coastal fortifications to repel naval attacks. But soon it became concerned with civil functions as it planned and executed the national internal improvement program initiated in the 1820s (Maass 1951).

Until the early 1800s, little maintenance or improvement was done to harbors or rivers, and maintaining navigability of waterways was considered the responsibility of the states or private interests. What little the Federal government had done was carried out by the Treasury Department, which had assisted navigation by erecting lighthouses, beacons, buoys, and public piers. In 1818, John C. Calhoun, then Secretary of War, recommended that the Corps of Engineers be directed to improve waterways navigation and other transportation systems because these civil works would facilitate the movement of the Army and its materials while contributing to national economic development (USACE 1978). Congress accepted Calhoun's recommendations and passed the landmark General Survey Act, which President James Monroe signed into law on April 30, 1824. It directed the President to use Army engineers to survey roads and canals. By the mid-1820s Corps of Engineers officers were busy surveying the Ohio and lower Mississippi Rivers and the Great Lakes, identifying navigation impediments, and proposing improvements and new routes.

Only a month later, on May 24, 1824, President Monroe signed the first Rivers and Harbors Act, which authorized the President to appropriate Federal monies to improve navigation on the Ohio and Mississippi Rivers. By 1829, Army engineers were using steam-powered snagboats to remove snags and floating trees and to dig out sandbars that impeded river traffic. Subsequent acts authorized a wide variety of internal improvements and assigned Army engineers to direct and manage these projects. Work soon began on a number of challenging locations that were deemed critical for the growth of a growing nation.

Hazardous navigation conditions on the Great Lakes also called for the rapid improvement of harbors. With the passage of the Rivers and Harbors Act, Congress voted a \$20,000 appropriation for deepening the channel at the harbor of Presque Isle (at Erie, Pennsylvania) on Lake Erie (Drescher 1982). Signaling the beginning of federal involvement in the development of harbors on the Great Lakes, the USACE now maintains over 600 navigation projects throughout these waterways.

One of the USACE's first civil projects on an ocean coast was repairing Long Beach at Plymouth, Massachusetts. The beach was a long, narrow sand spit that formed the town's harbor. Constantly endangered by waves and wind, it had been a subject of concern to the citizens of the town as early as 1702, when they made it a crime to fell its trees or fire the grass. The congressional appropriation of \$20,000 on May 26, 1824, "to repair Plymouth Beach in the state of Massachusetts, and thereby prevent the harbour at that place from being destroyed" initiated the Corps' civil works mission in New England. Corps officers supervised local agents, who built a cribwork breakwater along the beach's outer shore and erected brush fences and planted grass to stabilize the sand. Similar projects were undertaken at nearby Duxbury and other beaches in New England (Parkman 1978). The pattern whereby Corps specialists supervise local contractors has continued to this day for most civil works projects.

Over the succeeding century and a half, the USACE's role in civil works grew dramatically, in step with the growth of the nation's population and economy. To adequately cover this interesting story in the CEM would risk doubling its size, so readers are referred to a series of books that document the history of each district (Table I-3-1).

Presently, USACE officers and a large contingent of non-military government employees maintain a navigation system of more than 40,000 km (25,000 miles) and 219 locks and dams connecting large regions of the country. Of the nation's top 50 ports active in foreign waterborne commerce, over 90 percent require regular dredging (Waterborne Commerce Statistics Center 1999). Over 300 million cubic meters of dredged material are removed from navigation channels each year. In 1997, the USACE contracted for the dredging of about half this total (157 million m³, see Figure I-3-1) at coastal sites only. This does not include inland waterways (Hillyer 1996).

Most inlets and harbors used for commercial navigation in the United States are protected and stabilized by hard structures. The USACE built most of the structures and is responsible for maintaining even a larger number since the Federal Government assumed responsibility for some state and local projects. Figure I-3-2 summarizes the locations of the Federal projects (Hillyer 1996).

Many U.S. coastal urban and recreational centers are protected by erosion control and storm damage reduction projects constructed cooperatively by the USACE, state, and local governments (Figure I-3-3). Although most of the 83 Congressionally authorized shore protection projects are in densely developed areas, some were constructed primarily for recreation and are associated with public or park beaches (Sudar et al. 1995).

Table I-3-1
Selected Bibliography of USACE History

Region	Reference
General history of USACE	USACE 1998
Alaska District	Jacobs 1976
Atchafalaya Basin	Reuss 1998
Baltimore District	Kanarek 1978
Buffalo District	Drescher 1982
Charleston District	Moore 1981
Chicago District	Larson 1979
Detroit District	Larson 1981
Galveston District	Alperin 1977
Honolulu District	van Hoften 1970
Jacksonville District	Buker 1981
Little Rock District	Rathbun 1990
Los Angeles District	Turhollow 1975
Mobile District	Davis 1975
New England Division	Parkman 1986
New Orleans District	Cowdrey 1977
New York District	Klawonn 1977
North Atlantic Division	Chambers 1980
Ohio River Division	Johnson 1992
Pacific Ocean Division	Thompson 1981
Philadelphia District	Snyder and Guss 1974
Pittsburgh District	Johnson 1979
Portland District	Willingham 1983
San Francisco District	Hagwood 1982
Savannah District	Barber 1989
Seattle District	Seattle District 1969
St. Paul District	Merritt 1979
St. Lawrence Seaway	Becker 1984
St. Louis District	Dobney 1978
Wilmington District	Hartzer 1984

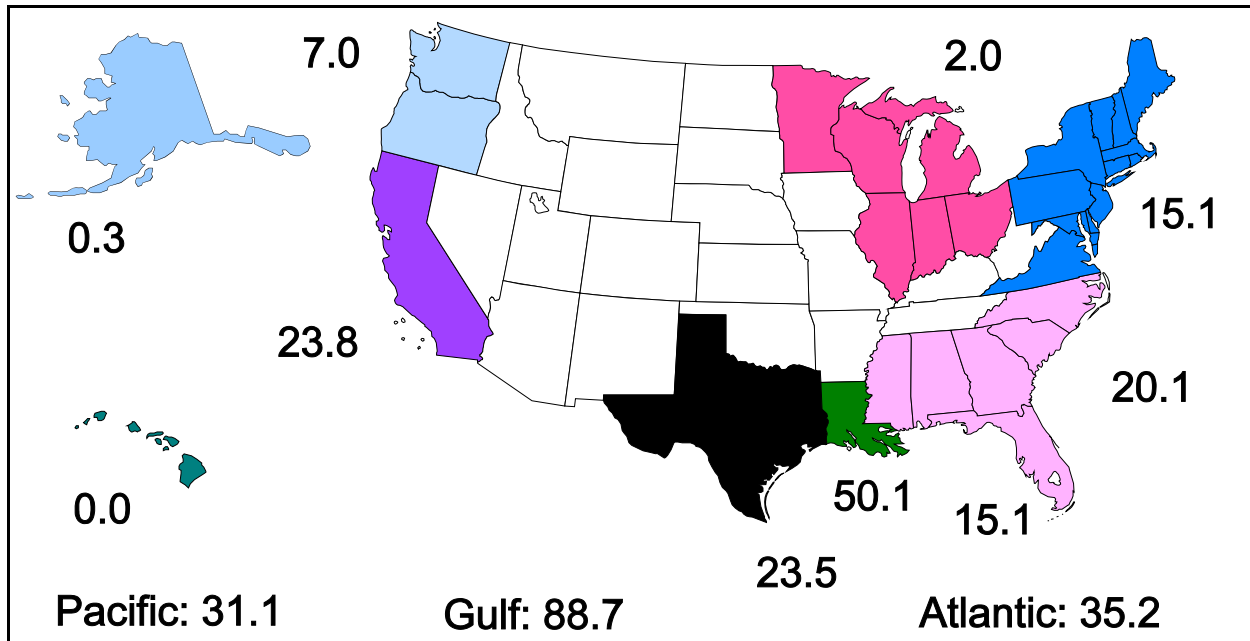


Figure I-3-1. Fiscal year 1997 dredging by the U.S. Army Corps of Engineers at coastal projects (million m³). These totals do not include dredging of inland waterways and rivers, but do include Great Lakes ports (from Hillyer 1996)

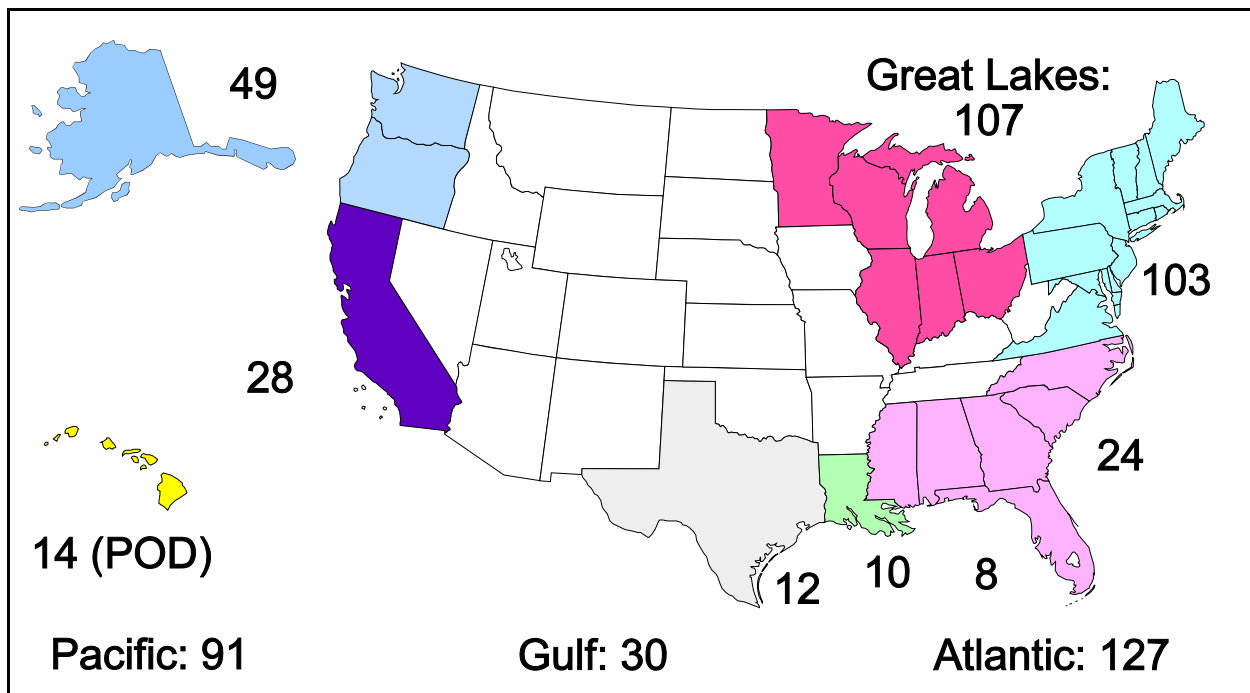


Figure I-3-2. Federally maintained deep-draft and small boat harbors with structures (from Hillyer 1996)

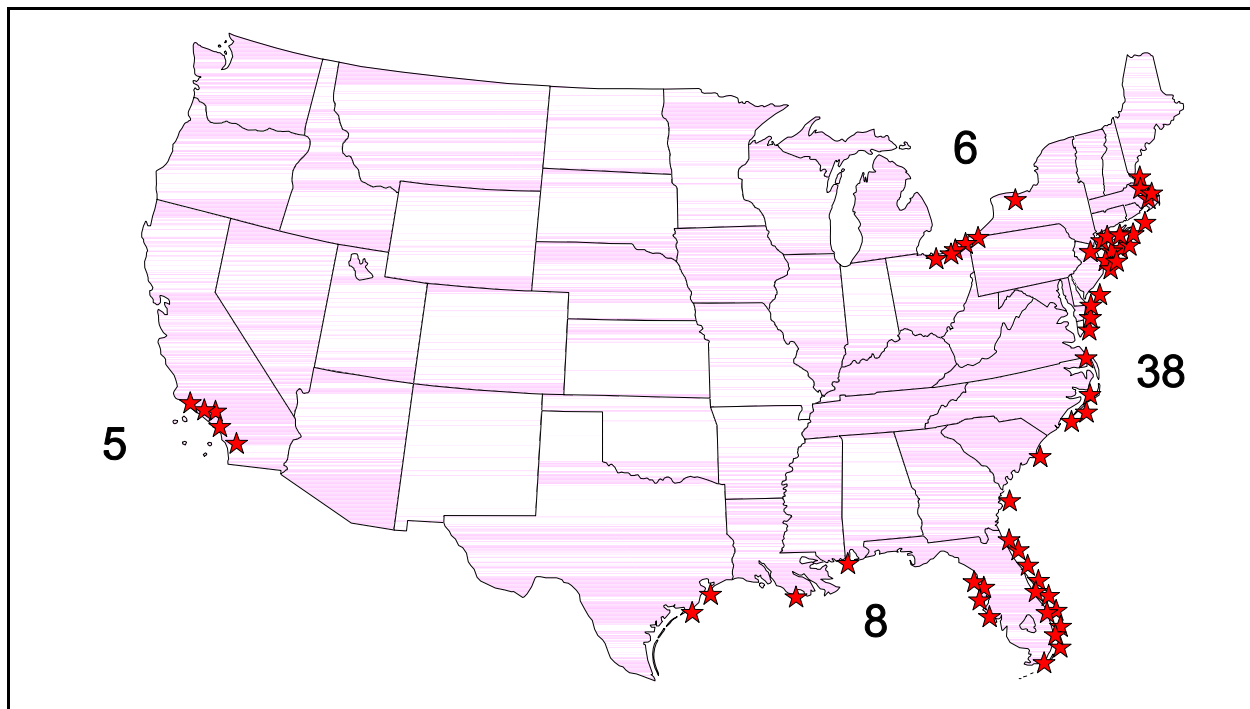


Figure I-3-3. Location of 57 large Congressionally authorized shore protection and beach erosion control projects. Some 26 small projects with limited scope and low cost (less than a few hundred thousand dollars) are not shown (from Hillyer 1996)

I-3-7. Coastal Engineering in the United States¹

a. *Nineteenth century projects.* From the birth of the United States through the 18th century, local and Federal coastal projects were designed to accommodate and facilitate growth. Harbors that were usable in their natural setting in the 18th century had to be improved during the industrial age to service the 19th century's larger, steam powered, ocean-going vessels. Though the Corps' attention focused on navigation-related improvements, its coastal activities ranged from beach reconstruction to blasting better shipping channels to building new ports and lighthouses. Some of the early projects are summarized below:

(1) Currents sweeping by Sullivan's Island, South Carolina, caused substantial erosion that threatened Fort Moultrie in the 1820s. A major reclamation program was started by the USACE under its authority to solve the erosion problems of existing fortifications (Moore 1982).

(2) Congress appropriated funds in 1826 for the Corps to combat erosion of valuable sand spits protecting Duxbury and Provincetown Harbors in Massachusetts and to construct jetties at Warren River and Martha's Vineyard to prevent sand from being carried by currents into the harbors (Parkman 1978).

(3) Attention of the United States Government was first directed to Erie Harbor at the close of the War of 1812. In 1823, the Board of Engineers presented an elaborate plan for improvement of the harbor's entrance. In May of 1824, Congress authorized improvements and protection of the vulnerable Presque Isle Peninsula (Goreki and Pope 1993). Engineering work continues at Presque Isle to this day (Figure V-3-10).

¹ One of the most detailed discussions of the history of coastal engineering in the United States is Weigel and Saville 1996.

(4) In 1830, Army Engineers surveyed and made recommendations for the improvement of Baltimore Harbor, Maryland. A prolonged program of channel improvement began in 1852, and by the summer of 1872, as many as 13 dredges were engaged in the excavation of the waterway. By the time of the Spanish-American war in 1898, Baltimore had become one of the world's major ports (Kanarek 1976 pp. 41-59).

(5) Buffalo, New York, and Cleveland, Ohio, grew from frontier villages to manufacturing and commercial centers in a little over a century because of their locations at the terminus of water and rail routes connecting the grain-rich areas of the west to the eastern urban centers. The economic lives of the two cities depended on the construction and maintenance of harbor facilities such as seawalls, jetties, breakwaters, and dredged channels. As a result of successive harbor improvement projects, they have become major cities on the Great Lakes (Drescher 1982). Much of the 19th century development of the mid-West and the Great Lakes occurred as European immigrants traveled through the port of New York, along the Erie Barge Canal through Buffalo, and on to points further west.

(6) Hell Gate, a one-mile section of the East River that connected Long Island Sound with New York Harbor, had very strong currents that sliced around rocks and islands and ran back and forth because the tides in the harbor and sound did not coincide. In 1845, New York city began an effort to open the East River to navigation and in 1852, the Corps tackled the immensely difficult task of developing new technology for underwater excavation and blasting that would be required to clear Hell Gate for navigation. The project was completed 30 years later (Klawonn 1977 pp. 69-93).

(7) In 1868, Congress responded to request for assistance from California that resulted in a long productive period of Federal, State, and local cooperation. The development of the California coast with rail connections to modern, deepwater ports at San Diego, Los Angeles, San Francisco, and Oakland was the ultimate result (Turhollow 1975 pp. 20-48).

(8) Following the devastating 1900 hurricane at Galveston, Texas, which drowned over 6,000 of its citizens, the city assigned three civilian engineers the task of developing the safest and most efficient means to protect the city from similar future floods. Based on their study, the city constructed a 5,360-meter (17,600-foot) curved face concrete seawall, (Figure V-3-5). The city was elevated several meters using sand pumped from Galveston Bay onto the beach behind the seawall. At the same time, Congress authorized a connecting seawall to protect the port and military reservation at Fort Crockett. The 4,900-ft extension was constructed from 1904 to 1905 (Alperin 1977, pp. 237-244).

b. Nineteenth century coastal engineering. In 19th century United States, most engineering in the coastal area consisted of the application of principles well known to engineers accustomed to dealing with rivers. There was little concern about the unique nature of the coast, and studies of the effects of wind and waves upon the shore were sporadic, desultory, and unscientific. Trial and error, frequently accompanied by innovation was the teaching tool of the day. Improvement of the St. Johns River mouth at Jacksonville, Florida provides a good example. A continuously shifting sinuous channel through the bar made navigation difficult, so in the 1850s, a citizens group petitioned the USACE for help in dealing with the sandbar problem. One solution proposed was to put the scouring power of the current to work by constructing jetties. The USACE engineers preferred to try clearing the channel by frequent dredging and raking during the strongest phase of the ebb. These attempts failed, and in 1878 influential citizens hired Captain James B. Eads to study the problem. The 1878 Eads report recommended constructing two converging jetties to create a stable deep channel out to sea. His report contained principles of seacoast engineering, sketches of the tidal prism, and estimates of the area that could be maintained. The sophisticated technology to confirm Eads' findings would not be available well into the 20th century. Largely as a result of Eads' success constructing the jetties at the mouth of the Mississippi River, the USACE adopted a modified version of his jetty plan for improving the St. Johns River entrance (Buker 1981, pp. 69-82) (Figure I-3-4).

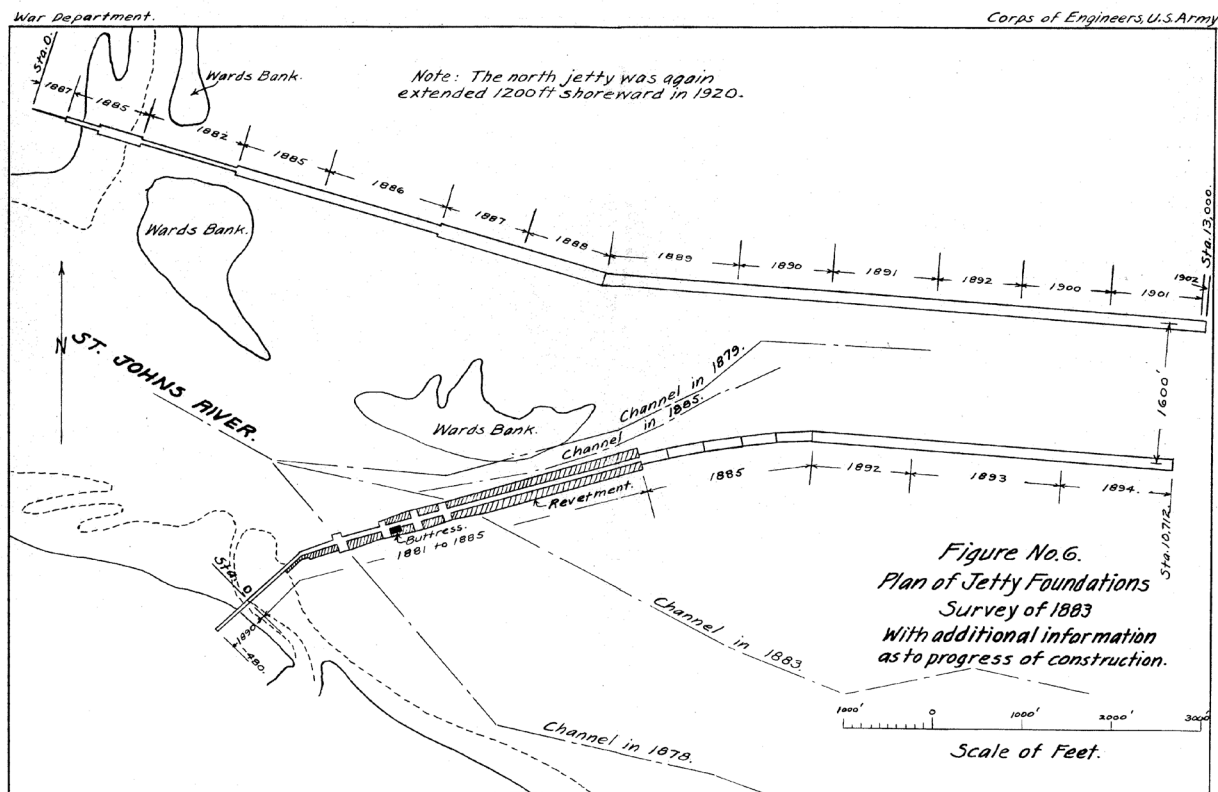


Figure I-3-4. Converging jetty system designed by James Buchanan Eads for the mouth of the St. Johns River, Florida. Figure courtesy of USAED, Jacksonville

Colonel Quincy Gillmore, familiar with Eads' plan for Jacksonville, used a similar plan to construct the jetties at Charleston Harbor, South Carolina, between 1878 and 1893. From the barrier islands on each side of the harbor entrance, the USACE constructed two converging jetties followed by a parallel section. The near shore portion of the jetties was constructed to just below the low tide water surface, thereby serving as a weir and allowing the flood tide to come in normally. During the ebb tide, the bottom currents were channeled through the parallel section (constructed higher, with the seaward quarter above high tide) toward the bar and this scouring action kept the new channel clear (Moore 1982). A similar plan was used at the mouth of the St. Mary's River at the Florida-Georgia border. Major George L. Gillespie, District Engineer in Portland, OR, submitted a plan for a dike at the mouth of the Columbia River to concentrate river currents and tides to scour a deep channel. Construction commenced on the south jetty in 1884, a project that had to overcome fierce winter storms and hazardous working conditions (Willingham 1983).

c. Early coastal development and shore protection. From the early days of settlement to the present, Americans have built in the coastal area. During the 1600 and 1700s, the original colonies owed their prosperity largely to the availability of good natural harbors, rich nearby fishing grounds, and active trade with the Caribbean and Europe. As the giant continent was explored and settled in the 1800s, rivers and the Great Lakes became the prime mode of moving goods and people to and from distant towns. In the 20th century, a new social phenomena arose that resulted in an ever-increasing interest in the coastal zone: more and more Americans achieved the economic means and leisure time to enjoy the beach for recreational purposes. Even before beaches became popular vacation destinations, engineers constructed structures to aid navigation, to halt erosion, and to protect shore front development from storm surge. They designed bulkheads, revetments, and seawalls to hold the shoreline in place. Generally, these designs were successful, with Galveston, Texas, and San Francisco, California, being two examples of early seawall construction. Other structures, such as groins and jetties, impeded longshore transport of sand. Groins are intended to

protect a finite beach section, while jetties keep sand out of the navigation channel between the jetties, define and maintains the harbor entrance channel, and provide calm water access to the harbor facilities (Figures I-3-5, I-3-6). For jetties built along uninhabited coastal areas in the 19th and early 20th centuries, the buildup of sand on the up-drift beach and the loss of sand on the downdrift beach was considered a minor consequence compared to the major benefits of ocean navigation trade (Figure I-3-7). In nearly every instance, these harbor structures interrupted the alongshore movement of sand and starved nearby downdrift beaches (USACE 1971), but it was not until the shore was developed in the later 20th century that this interruption of sand transport was regarded as a problem.

d. Early 20th century beach development and the Engineering Advisory Board on Coastal Erosion. As urbanization and congestion increased, the more affluent escaped to the seashore, where resorts arose to accommodate them. Until the age of the automobile, these resorts remained small isolated coastal enclaves tied to the hinterland by rails. The technical revolution brought electric trains, automobiles, gasoline-powered pleasure boats, labor-saving devices for the home, and a new era of leisure to a prospering nation (USACE 1971; Morison and Commager 1962). Electricity provided convenient power to energy-poor barriers. Changing morals allowed people to sunbathe and enjoy the hedonism of the beach experience. And with the growing use of the automobile, beach-goers in increasing numbers followed newly-built roads to the coast. Concern about shore erosion grew as more people acquired property and built homes and businesses, assuming a stable shoreline.

The New Jersey shore, close to the New York and Philadelphia urban areas, was one of the first highly developed shorelines (Figures I-3-8 and I-3-9). During the period 1915 to 1921, three hurricanes and four tropical storms battered the Jersey shore, causing severe beach erosion. In New Jersey, millions of dollars were spent on uncoordinated and sometimes totally inappropriate erosion control structures which often produced results that were only minimally effective, and, in some cases, counterproductive (Hillyer 1996). Engineers and city managers soon realized that individual property owners were incapable of dealing with coastal erosion and that a broader approach was necessary. In 1922, because of rapidly eroding shorelines and revenue losses to the coastal communities, the State funded and appointed an Engineering Advisory Board on Coastal Erosion. Its only recommendation was that further research was needed (Moore and Moore 1983).

In contrast to the haphazard development of the Jersey shore, some of the early large-scale coastal projects proved to be remarkably successful social and engineering accomplishments. America's first large engineered beach fill was the boardwalk and recreational beach on Coney Island in 1922 - 1923 (Farley 1923). With the completion of the project, immigrants and factory workers could escape the sweatshops of the sweltering city and enjoy a (crowded) Sunday at the beach for only a nickel subway ride (Figure I-3-10; Stanton 1999). This was followed by the ambitious construction of the Jones Beach Parkway by Robert Moses and the Long Island State Park Commission in 1926 - 1929, during which more than 30 million m³ of sand were pumped to create Jones Island (DeWan 1999; Kana 1999) (Figure I-3-11). In Chicago, the entire waterfront was reshaped between 1920 and 1940 with the addition of over 14.2 square km of fill, resulting in one of America's premier urban parks (Chrzastowski 1999). These were city- and state-sponsored projects, with minimal input by the Federal Government.

e. American Shore and Beach Preservation Association. Delegates (85) representing 16 states met at Asbury Park, New Jersey, in 1926, to discuss their growing coastal zone problems. After the first meeting, two more, following shortly thereafter, led to the formation of the American Shore and Beach Preservation Association (ASBPA). The Association brings together a cross section of engineers, public officials, State and Federal personnel, and coastal property owners. Their aim is that "Man must come to the rescue of the beaches." Members see themselves as leaders and teachers in a conservation movement to fight shore and beach erosion (Patton 1934). Their influence in State and Federal governments and continued interest in coastal zone issues is responsible for many of the laws and actions to protect the U. S. shores and beaches.